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June 29, 2006
BW060061

U. S. Nuclear Regulatory Commission
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Braidwood Station, Unit 1
Facility Operating License No. NPF-72
NRC Docket No. STN 50-456

Subject: Braidwood Station, Unit 1, 60-Day Response to First Revised NRC Order EA-03-009, "Issuance of First Revised NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors"

Reference: Letter from NRC, "Issuance of First Revised NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors" dated February 20, 2004

The purpose of this letter is to provide the results of examinations performed at Braidwood Station, Unit 1, in accordance with the requirements of the referenced NRC Order.

During the Spring 2006 (A1R12) refueling outage, Braidwood Station, Unit 1, completed both the nonvisual volumetric nondestructive examination in accordance with Order Section IV. C. (5) (b) and the visual inspection to identify potential boric acid leaks from pressure-retaining components above the reactor pressure vessel (RPV) in accordance with Section IV, paragraph D of the Order.

Section IV. E. of the Order requires that the results of this examination be submitted to the NRC within 60 days after returning the plant to operation. The Braidwood Station, Unit 1, Spring 2006 refueling outage ended on May 3, 2006 and therefore the inspection results must be submitted by July 2, 2006.

Detailed reports describing the examination results are provided in two attachments to this letter. In summary, there were no indications of cracking in any of the penetrations, and there was no evidence of a leakage path along the reactor vessel head penetration shrink-fit regions. Note that ten penetrations (i.e., numbers 42, 49, 54, 63, 65, 66, 71, 72, 77, and 78), which had limited inspection coverage due to the physical length of the penetration tube, will require a relaxation request.

The examination of one penetration (number 74) was limited circumferentially (approximately 60 degrees) due to the surface condition of the inside diameter surface of the penetration tube causing probe lift-off. EGC will also submit a relaxation request to address the lack of coverage for this penetration.

The visual inspection performed in accordance with Section IV, paragraph D of the Order did not identify any boric acid leaks from pressure-retaining components above the RPV head or any boron deposits on the mirror insulation above the RPV head.

Should you have any questions or desire additional information regarding this letter, please contact Mr. Dale Ambler, Regulatory Assurance Manager, at (815) 417-2800.

Respectfully,

Keith J. Polson

Keith J. Polson
Site Vice President
Braidwood Nuclear Generating Station

Attachments: 1) A1R12 Reactor Pressure Vessel Head Visual Inspection Results
2) Braidwood Unit 1 – A1R12 Reactor Vessel Head Penetration Examination/Westinghouse Report WDI-PJF-1303195-FSR-001

# ATTACHMENT 1

## A1R12 Reactor Vessel Head Visual Inspection Results

## ATTACHMENT 1
## A1R12 Reactor Vessel Head Visual Inspection Results

The visual examinations performed on the Braidwood Unit 1 reactor pressure vessel (RPV) head during the Spring 2006 refueling outage are contained in the first revised NRC Order EA-03-009 (Order), Section IV. D, which states:

> ***"During each refueling outage, visual inspections shall be performed to identify potential boric acid leaks from pressure-retaining components above the RPV head. For any plant with boron deposits on the surface of the RPV head or related insulation, discovered either during the inspections required by this Order or otherwise and regardless of the source of the deposit, before returning the plant to operation the Licensee shall perform inspections of the affected RPV head surface and penetrations appropriate to the conditions found to verify the integrity of the affected area and penetrations."***

### VISUAL EXAMINATION RESULTS

During the Braidwood Station Unit 1 Spring 2006 refueling outage (A1R12), walk downs were performed with the unit in Mode 3, shortly after reactor shutdown. The walk downs were performed in accordance with the requirements of the Braidwood Station Boric Acid Corrosion Control program and paragraph IV. D of the Order. No evidence of reactor coolant leakage or degradation associated with boric acid leakage was noted during these walk downs.

**ATTACHMENT 2**

**Westinghouse Report WDI-PJF-1303195-FSR-001**

**"Braidwood Unit 1 – A1R12**
**Reactor Vessel Head Penetration Examination**
**April 2006"**

**ATTACHMENT 2**
**Braidwood Unit 1 – A1R12**
**Reactor Vessel Head Penetration Examination**

The nonvisual NDE examinations (ultrasonic and eddy current) performed on the Braidwood Station Unit 1 reactor pressure vessel (RPV) head during the Spring 2006 refueling outage are contained in the first revised NRC Order EA-03-009 (Order), Section IV, paragraphs C.(3) and C.(5)(b).

Paragraph IV.C.(3) of the Order states:

> ***"...The requirements of paragraph IV.C.(5)(b) must be completed at least once prior to February 11, 2008, and thereafter, at least every 4 refueling outages or every 7 years, whichever occurs first."***

Paragraph IV.C.(5)(b) of the Order states:

> ***"For each penetration, perform a nonvisual NDE in accordance with either (i), (ii) or (iii):***
>
> ***(i) Ultrasonic testing of the RPV head penetration nozzle volume (i.e., nozzle base material) from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 2 inches [see Figure IV-1]); OR from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.0-inch below the lowest point at the toe of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level (including all residual and normal operation stresses) of 20 ksi tension and greater (see Figure IV-2). In addition, an assessment shall be made to determine if leakage has occurred into the annulus between the RPV head penetration nozzle and the RPV head low-alloy steel.***
>
> ***(ii) Eddy current testing or dye penetrant testing of the entire wetted surface of the J-groove weld and the wetted surface of the RPV head penetration nozzle base material from at least two inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 2 inches [see Figure IV-3]; OR from 2 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.0-inch below the lowest point at the toe of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level (including all residual and normal operation stresses) of 20 ksi tension and greater (see Figure IV-4).***

***(iii)*** ***A combination of (i) and (ii) to cover equivalent volumes, surfaces and leak paths of the RPV head penetration nozzle base material and J-groove weld as described in (i) and (ii). Substitution of a portion of a volumetric exam on a nozzle with a surface examination may be performed with the following requirements:***

1. ***On nozzle material below the J-groove weld, both the outside diameter and inside diameter surfaces of the nozzle must be examined.***

2. ***On nozzle material above the J-groove weld, surface examination of the outside diameter surface of the nozzle is permitted provided a surface examination of the J-groove weld is also performed."***

The ultrasonic and eddy current examinations for Braidwood Unit 1 required by the Order were performed by Westinghouse. There were no indications of cracking in any of the penetrations and there was no evidence of a leakage path along the reactor vessel head penetration shrink-fit regions. Detailed discussion of the examinations performed and results are contained in Westinghouse report WDI-PJF-1303195-FSR-001 that is attached. The referenced Examination Procedures, Technical Justifications, Calibration and Examination Data, and Volumes 2 and 3 are not included in the attached report.

The following terms are referenced in the Westinghouse report:

| Acronym | Term |
|---|---|
| BBP | B and B Prime |
| BWP | Backwall Perturbation |
| CBH | Cleared By History |
| IPA | Indication Profile Analysis |
| LOL | Lack of Lateral Wave |
| MAI | Multiple Axial Indications |
| MCI | Multiple Circumferential Indications |
| NDD | No Detectable Defect |
| PTI | Penetration Tube Indication |
| PVI | Permeability Variation Indication |
| SAI | Single Axial Indication |
| SCI | Single Circumferential Indication |
| SGI | Surface Geometry Indication |
| SSS | Shallow Surface Scratch |
| WVI | Weld Volume Indication |

# Braidwood Unit 1 – A1R12 Reactor Vessel Head Penetration Examination

## April 2006

# Final NDE Report

## WDI-PJF-1303195-FSR-001

Westinghouse Electric Company
Nuclear Services
Waltz Mill Service Center
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# 1.0 INTRODUCTION

During the Braidwood Unit 1 A1R12 outage in the spring of 2006, Westinghouse performed nondestructive examinations (NDE) of the seventy-eight control rod drive mechanism (CRDM) penetration tubes and the vent line in the reactor vessel head.

The purpose of the examination program was to identify evidence of primary water stress corrosion cracking (PWSCC) that might be present on the outside diameter (OD) and inside diameter (ID) surfaces of the head penetration tubes and to assess whether leakage might have occurred into the annulus at the tube-to-head interface. Examinations were performed using procedures and techniques demonstrated through the EPRI/MRP protocol [1] and/or Westinghouse internal demonstration programs, and applied consistent with the requirements of the February 20, 2004, first revision to USNRC Order EA-03-009, "Establishing Interim Inspection Requirements for Reactor Vessel Heads at Pressurized Water Reactors" [2].

The Braidwood reactor vessel head is a Westinghouse design. The head was manufactured by Babcock & Wilcox (B&W) in Mt. Vernon, IN. The alloy 600 penetration tubes are shrunk fit into the reactor vessel head and attached with alloy 182/82 partial penetration J-groove welds. The vent line is an alloy 600 tube attached to the reactor vessel head with an alloy 182/82 partial penetration weld.

The penetration tubes in the Braidwood reactor vessel head are machined from heats of material supplied by B&W Tubular Products. The penetration tubes measure 4.0" on the OD and have an ID dimension of 2.75". The vent line, 1" schedule 160, has a nominal wall thickness of 0.25" and a nominal OD of 1.315".

A summary of the heats of material in the head is provided in Table 1-1.

**Table 1-1: Braidwood Unit 1 RV Head Penetration Material Heats**

| Material Supplier | Heat # |
|---|---|
| B&W | 90745 |
| B&W | 90877 |
| B&W | 90704 |
| B&W | 90878 |
| B&W | 80059 |
| B&W | 91112 |
| B&W | 90862 |

There are a variety of configurations for the 78 penetration tubes, each configuration requiring special consideration for examination. The penetration tube configurations are as follows:

- Fifty-three penetration tubes with thermal sleeves installed
- Two heat junction thermocouple locations with modified thermal sleeves installed
- Twenty-three penetration locations without thermal sleeves

The Braidwood reactor vessel head is in the "low susceptibility" category as defined in the first Revision to USNRC Order EA-03-009.

Paragraph IV.C (5) of the first Revision to USNRC Order EA-03-009 specifies:

*a) Bare metal visual examination of 100% of the RPV head surface (including 360$^{O}$ around each RPV head penetration nozzle), and*

*b) For each penetration, perform a nonvisual NDE in accordance with either i, ii or iii:*

*i. Ultrasonic testing of each RPV head penetration nozzle volume (i.e., nozzle base material) from two (2) inches above the highest point of the root of the J-groove weld to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis; OR from 2 inches above the highest point of the root of the J-groove weld to 1 inch below the lowest point at the toe of the J-groove weld and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level of 20 ksi tension and greater. In addition, an assessment shall be made to determine if leakage has occurred into the annulus between the RPV head penetration nozzle and the RPV head low alloy steel.*

*ii. Eddy current or dye penetrant testing of the entire wetted surface of the J-groove weld and the wetted surface of the RPV head penetration nozzle base material from at least 2 inches above the highest point of the root of the J-groove weld to 2 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis; OR from 2 inches above the highest point of the root of the J-groove weld to 1 inch below the lowest point at the toe of the J-groove weld and including all RPV head penetration nozzle surfaces below the J-groove weld that have an operating stress level of 20 ksi tension and greater.*

*iii. A combination of (i) and (ii) to cover equivalent volumes, surfaces and leak paths of the RPV head penetration nozzle base material and J-groove welds described in (i) and (ii).*

For plants in the low susceptibility category, inspections specified in paragraph IV.C (5) (a) are required every third refueling outage or every 5 years, whichever comes first. If an inspection meeting the requirements of paragraph IV.C (5) (a) was not performed during the last refueling outage prior to February 11, 2003, an inspection meeting those requirements is required within the first 2 refueling outages after February 11, 2003. An inspection meeting the requirements of paragraph IV.C (5) (b) is required at least once prior to February 11, 2008 and at least every 4 refueling outages or every 7 years, whichever comes first, thereafter.

The examination program selected for Braidwood during the A1R12 outage included ultrasonic examinations of the 78 CRDM penetration nozzles with leakage assessment in accordance with paragraph IV.C (5) (b) (i) of the Revised NRC Order. For the vent line, the wetted surface examination option using eddy current techniques was selected in accordance with Section IV.C (5) (b) (ii) of the Revised NRC Order. .

Stress distribution curves were developed in advance of the examination which identified the hoop stress distributions below the attachment welds on the OD surfaces of penetration tubes. A fracture analysis was performed and the results were presented in the form of flaw tolerance charts for both surface and through wall flaws. If indications of PWSCC had been identified, the charts were available to determine the allowable safe operation service life [3].

A contingency plan was in place to address geometric conditions at penetration locations where access of the Trinity blade probes in the penetration/tube annulus might be limited. The contingency plan included equipment and procedures necessary to perform wetted surface examinations in accordance with Section IV.C (5) (b) (ii) of the Revised Order.

The following Westinghouse field service procedures and field change notices (FCNs) were approved for use at Braidwood Unit 1.

- WDI-ET-002, Rev. 7 – "Eddy Current Inspection of J-Groove Welds in Vessel Head Penetrations"

- WDI-ET-003, Rev. 9 – "IntraSpect Eddy Current Imaging Procedure for Inspection of Reactor Vessel Head Penetrations"

- WDI-ET-004, Rev. 10 – "IntraSpect Eddy Current Analysis Guidelines"

- WDI-ET-008, Rev. 7 – "IntraSpect Eddy Current Imaging Procedure for Inspection of Reactor Vessel Head Penetrations With Gap Scanner"

- WDI-UT-010, Rev. 12 - "IntraSpect Ultrasonic Procedure for Inspection of Reactor Vessel Head Penetrations, Time of Flight Ultrasonic & Longitudinal Wave & Shear Wave"

- WDI-UT-013, Rev. 10 – “IntraSpect UT Analysis Guidelines”
- WDI-STD-101, Rev. 5 – “RVHI Vent Tube J-Weld Eddy Current Examination”
- WDI-STD-114, Rev. 4 – “RVHI Vent Tube ID & CS Wastage Eddy Current Examination”
- WDI-STD-151, Rev.1- “Reactor Vessel Head Inspection for Byron Units 1&2 CAE/CBE and Braidwood Units 1&2 CCE/CDE”
- WCAL-002, Rev. 7– “Pulser/Receiver Linearity Procedure”

## 2.0 SCOPE OF WORK

The reactor vessel head penetration examination scope at Braidwood included all seventy-eight CRDM penetration tubes and the vent line.

The examination methodology selected for each penetration was dependent upon the penetration tube configuration and penetration-specific conditions.

1. Twenty-three penetration tubes without thermal sleeves were examined from the ID using the Westinghouse 7010 Open Housing Scanner (OHS).
2. Fifty-five penetration tubes; fifty-three with thermal sleeves and two heat junction thermocouple locations, were examined from the ID using the Westinghouse Gapscanner and Trinity blade probes.
3. The vent line tube eddy current examination was performed with an array of 16 plus-Point probes and a low frequency bobbin coil. The vent line J-groove weld eddy current examination was performed with an array of 28 plus-Point coils.

The delivery system used for the CRDM examinations was the Westinghouse DERI 700 manipulator.

The DERI 700 is a multi-purpose robot that can access all head penetrations and provides a common platform for all CRDM examination end effectors. The manipulator consists of a central leg, mounted on a carriage, which in turn is mounted onto a guide rail. The manipulator arm, with elbow and removable wrist, is mounted onto the carriage, which travels vertically along the manipulator leg.

The DERI 700 was used to deliver 1) the Westinghouse 7010 Open Housing Scanner for ultrasonic and 2) supplementary eddy current examinations of open penetration locations and the Westinghouse Gapscanner end effector for Trinity probe examinations of penetration locations containing thermal sleeves.

The Westinghouse 7010 Open Housing Scanner delivers an examination wand containing ultrasonic and eddy current probes to the ID surface of open reactor vessel head penetrations. The scanning motion is in a vertical direction moving from a specified height above the weld, in this case at least 2.0", to the bottom of each penetration. The probe is indexed in the circumferential direction. With the open housing scanner, multiple examination probes are delivered simultaneously. These include time-of-flight diffraction ultrasonic (TOFD-UT) probes oriented in the axial and circumferential directions, $0^{o}$ ultrasonic probe to identify variations in the penetration tube-to-reactor vessel head shrink fit area that might indicate a leak path in the annulus between the tube and the head, and a supplementary eddy current probe for identification of circumferential and axial degradation on the ID surfaces of the penetration tubes

The Gapscanner end effector delivers Trinity blade probes into the annulus between the ID surface of the head penetration tube and the OD surface of the thermal sleeve. The typical annulus size is 0.125". The Trinity blade probes include a TOFD UT transducer pair for detection of axial and circumferential degradation, a $0^{o}$ ultrasonic transducer to identify variations in the penetration tube-to-reactor vessel head shrink fit area that might indicate a leak path in the annulus between the tube and the head, and a supplementary crosswound eddy current coil. The scanning motion is in a vertical direction moving from a specified height above the weld, in this case at least 2.0", to the bottom of each penetration. The probes are indexed in the circumferential direction.

## 2.1 CRDM Penetration Tube Ultrasonic and Supplementary Eddy Current Examinations from the Tube ID

All seventy-eight penetration tubes were ultrasonically examined from the tube ID surface in accordance with Section IV.C (5) (b) (i) of the Revised NRC Order. Methods for leakage assessment were incorporated into these examinations.

### 2.1.1 CRDM Penetration Tube 7010 Open Housing Scanner Examinations

7010 Open Housing Scanner examinations were conducted on twenty-three reactor vessel head penetrations without thermal sleeves.

Examinations of these vessel head penetrations included:

1. TOFD ultrasonic techniques in accordance with WDI-UT-010, Rev. 12 – "IntraSpect Ultrasonic Procedure for Inspection of Reactor Vessel Head Penetrations, Time of Flight Ultrasonic Longitudinal Wave" & Shear Wave",

2. straight beam ultrasonic techniques to identify possible leak paths in the shrink fit region between the head penetrations and the reactor vessel head, also in accordance with WDI-UT-010, Rev. 12, and

3. supplementary eddy current examinations on the penetration tube ID surfaces in accordance with and WDI-ET-003, Rev. 9 - "IntraSpect Eddy Current Imaging Procedure for Inspection of Reactor Vessel Head Penetrations".

### 2.1.2 CRDM Penetration Tube Gapscanner Trinity Probe Examinations

Examinations were performed with the Gapscanner end effector and Trinity probes on fifty-five penetration tubes; fifty-three with thermal sleeves and two heat junction thermocouple locations, from the penetration ID surfaces.

Examinations of these vessel head penetrations included:

1. TOFD ultrasonic techniques in accordance with WDI-UT-010, Rev. 12 – "IntraSpect Ultrasonic Procedure for Inspection of Reactor Vessel Head Penetrations, Time of Flight Ultrasonic Longitudinal Wave" & Shear Wave",

2. straight beam ultrasonic techniques to identify possible leak paths in the shrink fit region between the head penetrations and the reactor vessel head, also in accordance with WDI-UT-010, Rev. 12, and

3. supplementary eddy current examinations in accordance with and WDI-ET-008, Rev. 7 - "IntraSpect Eddy Current Imaging Procedure for Inspection of Reactor Vessel Head Penetrations".

## 2.2 Eddy Current Wetted Surface Examinations

Wetted surface examinations were conducted on the vent line and the vent line weld using eddy current techniques in accordance with Section IV.C (5) (b) (ii) of the Revised NRC Order.

### 2.2.1 Vent Line Tube ID and J-Weld Eddy Current Examinations

The vent line tube eddy current examination was performed with an array of 16 plus-Point probes and a low frequency bobbin coil in accordance with WDI-STD-114, Rev. 4 - "Head Vent ID Eddy Current Inspection". The vent line J-groove weld eddy current examination was performed with an array of 28 plus-Point coils in accordance with WDI-STD-101, Rev. 5, "RVHI Vent Tube J-Weld Eddy Current Examination".

# 3.0 EXAMINATION RESULTS

## 3.1 CRDM Penetration Tube Ultrasonic and Supplementary Eddy Current Examinations from the Tube ID

Table 3-1 provides a summary of results from the 7010 Open Housing Scanner reactor vessel head penetration nondestructive examinations.

**Table 3-1: Open Housing Scanner Examination Results**

| Penetration # | Circ TOFD | Axial TOFD | Leak Path Assessment | Supplementary Tube ID ECT |
|---|---|---|---|---|
| 10 | NDD | NDD | NDD | NDD |
| 11 | NDD | NDD | NDD | NDD |
| 12 | NDD | NDD | NDD | NDD |
| 13 | PTI/BBP/NDD | PTI/BBP/NDD | NDD | NDD |
| 18 | NDD | NDD | NDD | NDD |
| 19 | PTI/BBP/NDD | PTI/BBP/NDD | NDD | NDD |
| 20 | NDD | NDD | NDD | NDD |
| 21 | NDD | NDD | NDD | NDD |
| 22 | NDD | NDD | NDD | SSS/NDD |
| 23 | NDD | NDD | NDD | NDD |
| 24 | NDD | NDD | NDD | NDD |
| 25 | NDD | NDD | NDD | NDD |
| 26 | NDD | NDD | NDD | NDD |
| 27 | NDD | NDD | NDD | NDD |
| 28 | NDD | NDD | NDD | NDD |
| 29 | NDD | NDD | NDD | NDD |
| 62 | NDD | NDD | NDD | NDD |
| 64 | NDD | NDD | NDD | NDD |
| 74 | LCG/NDD | LCG/NDD | NDD | SSI/NDD |
| 75 | NDD | NDD | NDD | NDD |
| 76 | NDD | NDD | NDD | NDD |
| 77 | NDD | NDD | NDD | NDD |
| 78 | NDD | NDD | NDD | NDD |

***Legend***
***BBP: B and B Prime***
***IPA: Indication Profile Analysis***
***NDD: No Detectable Defect***
***PTI: Penetration Tube Indication***
***LCG: Loss of Contact due to Geometry***
***SSI: Surface Scratch Indication***
***SSS: Shallow Surface Scratch***

No detectable degradation characteristic of PWSCC was reported in any of the penetrations examined with the 7010 Open Housing Scanner. There was no evidence of leakage in the annulus between the penetration nozzles and the reactor vessel head.

Table 3-2 provides a summary of results from Gapscanner examinations performed with Trinity Probes.

**Table 3-2: Trinity Probe Examination Results**

| Penetration # | PCS24 TOFD | 0° Leak Path | Supplementary Tube ID ECT |
|---|---|---|---|
| 1 | NDD | NDD | NDD |
| 2 | NDD | NDD | NDD |
| 3 | NDD | NDD | SGI/NDD |
| 4 | PTI/BBP/NDD | NDD | NDD |
| 5 | NDD | NDD | NDD |
| 6 | NDD | NDD | SGI/NDD |
| 7 | PTI/BBP/NDD | NDD | NDD |
| 8 | PTI/IPA/LCG/NDD | LCG/NDD | NDD |
| 9 | NDD | NDD | NDD |
| 10 | ------* | ------* | ------* |
| 11 | ------* | ------* | ------* |
| 12 | ------* | ------* | ------* |
| 13 | ------* | ------* | ------* |
| 14 | PTI/BBP/NDD | NDD | NDD |
| 15 | NDD | NDD | NDD |
| 16 | NDD | NDD | NDD |
| 17 | NDD | NDD | NDD |
| 18 | ------* | ------* | ------* |
| 19 | ------* | ------* | ------* |
| 20 | ------* | ------* | ------* |
| 21 | ------* | ------* | ------* |
| 22 | ------* | ------* | ------* |
| 23 | ------* | ------* | ------* |
| 24 | ------* | ------* | ------* |
| 25 | ------* | ------* | ------* |
| 26 | ------* | ------* | ------* |
| 27 | ------* | ------* | ------* |
| 28 | ------* | ------* | ------* |
| 29 | ------* | ------* | ------* |
| 30 | NDD | NDD | NDD |
| 31 | NDD | NDD | NDD |
| 32 | NDD | NDD | CCG/NDD |
| 33 | NDD | NDD | NDD |
| 34 | NDD | NDD | NDD |
| 35 | PTI/IPA/NDD | NDD | NDD |
| 36 | NDD | NDD | NDD |
| 37 | NDD | NDD | NDD |
| 38 | PTI/IPA/NDD | NDD | NDD |
| 39 | NDD | NDD | NDD |
| 40 | NDD | NDD | NDD |
| 41 | NDD | NDD | NDD |

| Penetration # | PCS24 TOFD | 0° Leak Path | Supplementary Tube ID ECT |
|---|---|---|---|
| 42 | NDD | NDD | NDD |
| 43 | NDD | NDD | NDD |
| 44 | NDD | NDD | NDD |
| 45 | PTI/IPA/NDD | NDD | NDD |
| 46 | PTI/BBP/NDD | NDD | NDD |
| 47 | PTI/IPA/NDD | NDD | NDD |
| 48 | NDD | NDD | SGI/NDD |
| 49 | PTI/BBP/NDD | NDD | NDD |
| 50 | NDD | NDD | NDD |
| 51 | PTI/BBP/NDD | NDD | NDD |
| 52 | PTI/BBP/IPA/NDD | NDD | NDD |
| 53 | NDD | NDD | NDD |
| 54 | PTI/BBP/NDD | NDD | NDD |
| 55 | PTI/BBP/NDD | NDD | NDD |
| 56 | NDD | NDD | NDD |
| 57 | PTI/IPA/NDD | NDD | NDD |
| 58 | NDD | NDD | NDD |
| 59 | NDD | NDD | NDD |
| 60 | LCG/NDD | NDD | NDD |
| 61 | NDD | NDD | NDD |
| 62 | ------* | ------* | ------* |
| 63 | NDD | NDD | NDD |
| 64 | ------* | ------* | ------* |
| 65 | NDD | NDD | CCG/NDD |
| 66 | PTI/IPA/NDD | NDD | NDD |
| 67 | NDD | NDD | NDD |
| 68 | NDD | NDD | NDD |
| 69 | NDD | NDD | NDD |
| 70 | NDD | NDD | NDD |
| 71 | NDD | NDD | NDD |
| 72 | NDD | NDD | NDD |
| 73 | NDD | NDD | NDD |
| 74 | ------* | ------* | ------* |
| 75 | ------* | ------* | ------* |
| 76 | ------* | ------* | ------* |
| 77 | ------* | ------* | ------* |
| 78 | ------* | ------* | ------* |
| 79 | ------* | ------* | ------* |

*Legend*
*BBP: B and B Prime*
*IPA: Indication Profile Analysis*
*NDD: No Detectable Defect*
*PTI: Penetration Tube Indication*
*LCG: Loss of Contact due to Geometry*
*CCG: Craze Cracking Geometry*
*SGI: Surface Geometry Indication*

***------* : Indicates Penetrations Examined With the Open Housing Scanner***

No detectable degradation characteristic of PWSCC was reported in any of the penetration tubes examined with the Trinity Probes. There was no evidence of leakage in the annulus between the penetration nozzles and the reactor vessel head.

## 3.2 Eddy Current Wetted Surface Examinations

### 3.2.2 Vent Line Tube and J-Weld Eddy Current Examinations

Results of the eddy current examinations of the vent line and vent line J-groove weld are summarized in Table 3-4.

**Table 3-4 Vent Tube and J-Groove Weld Eddy Current Results**

| Penetration # | Array ECT Results |
|---|---|
| Vent Line Weld | NDD |
| Vent Line Tube | NDD |

***Legend***

***NDD: No Detectable Degradation***

No detectable degradation characteristic of PWSCC was identified during the eddy current examinations of the vent line J-groove weld and the vent line tube ID surface.

## 4.0 EXAMINATION COVERAGE

## 4.1 Penetration Tube Configuration and Examination Summary

The configuration of a sleeved Braidwood CRDM penetration tube is illustrated in Figure 4-1. This figure represents the tube-to-head geometry at the penetration $0^{\circ}$ azimuth, or "downhill" side of the tube. The bottom ends of all penetration tubes are threaded on the OD surface and have a chamfer on the ID surface. The threads extend from the bottom of the tube to an elevation of approximately 1.00" where a thread relief is machined. The top of the thread relief is 1.13" above the bottom of the tube. The distance from the top of the thread relief to the bottom of the fillet of the J-groove weld, identified as "A", varies based on location of the penetration in the head. These distances are generally longer for penetrations at "inboard" locations and become progressively shorter for penetrations located further away from the center of the head. The ID surface chamfers are machined at a $20^{0}$ angle from the bottom of the tube to an elevation of 0.76".

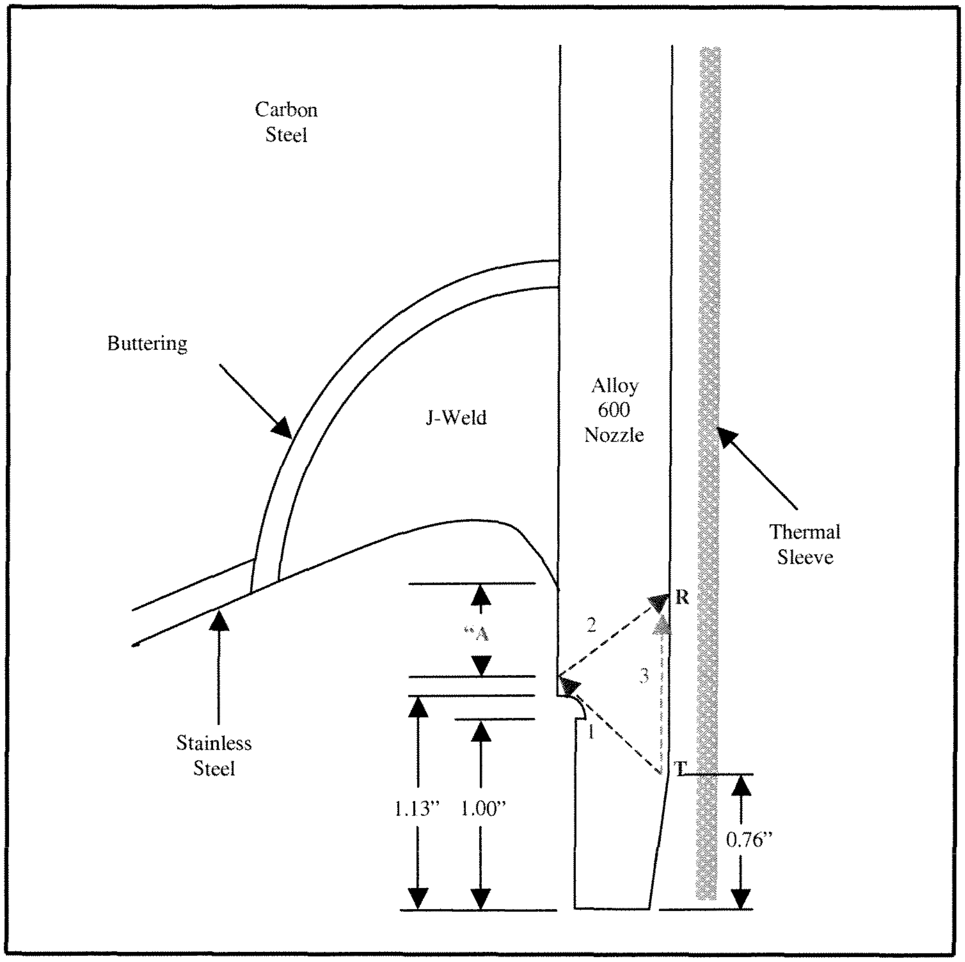



**Figure 4-1: Illustration of Axially Oriented TOFD Examination Coverage on Braidwood Unit 1 Penetration Geometry at 0° (Downhill Side)**

## 4.2 Ultrasonic Testing Coverage in Accordance With Section IV.C (5) (b) (i) of the Revised NRC Order

The ultrasonic method demonstrated through the EPRI/MRP Protocol for detection of circumferential and axial degradation on the OD and ID surfaces of CRDM penetration tubes is the time-of-flight diffraction (TOFD) technique. The TOFD technique is a "pitch/catch" ultrasonic method, where longitudinal waves are transmitted into the tube at an angle by a transmitter (T) and reflects off of the backside of the tube to a receiver (R), as shown in path "1-2" in Figure 4-1. A lateral wave also travels on the tube ID surface between the transmitter and receiver as shown in path "3". The transmitting and receiving elements are mounted on a "shoe" with a probe center spacing of 0.925". ID TOFD coverage is provided by the lateral wave to the elevation of the chamfer the tube on the ID surface. With an axially oriented TOFD transducer pair in the Trinity Probe, OD coverage becomes completely effective at an elevation just above the top of the thread relief.

The presence of the thread relief results in a slight masking of the ultrasound to the OD surface to an elevation conservatively estimated at 0.20" above the thread relief. In this area, however, OD initiated degradation would be detected once the depth of the degradation exceeded the depth of the masked area. With a circumferentially oriented TOFD transducer pair, included in the Open Housing Scanner, OD coverage is extended to the elevation of the top of the chamfer, approximately 0.76" above the bottom of the tube. In the threaded region, cracks extending deeper than the threads will be detected.

Examination coverage on the ID surfaces of the fifty-five penetration tubes examined with Trinity Probes and twenty-three penetration tubes examined with the Open Housing Scanner extended from the top of the chamfer in each tube to at least 2.0" above the uppermost elevation of the weld. The extent of coverage was verified for each penetration by 1) confirmation that tube entry signals at the elevation of the chamfer were evident in the eddy current and ultrasonic data, and 2) direct measurements from the TOFD UT C-scans which demonstrated scan coverage elevations were in excess of 2.0" above the uppermost elevation of each weld.

Examination coverage on the OD surfaces of the twenty-three penetration tubes examined with the Open Housing Scanner extended from the top of the chamfer in each tube to at least 2.0" above the uppermost elevation of the weld. For those tubes examined with Trinity Probes OD coverage extended from just above the elevation of the thread relief to at least 2.0" above the welds. The extent of coverage was verified for each examination of each penetration by 1) confirmation that TOFD responses were evident from the thread relief and 2) direct measurements from the TOFD UT C-scans which demonstrated scan coverage elevations were in excess of 2.0" above the uppermost elevation of each weld.

Examination coverage measured for each penetration location during the spring 2006 examination program is provided in Appendix A.

## 5.0 DISCUSSION OF RESULTS

Penetration tube ultrasonic examination data were analyzed in accordance with WDI-UT-013, Rev. 10 – "IntraSpect UT Analysis Guidelines". Eddy current data were analyzed in accordance with WDI-ET-004, Rev. 10 – "IntraSpect Eddy Current Analysis Guidelines Inspection of Reactor Vessel Head Penetrations". The screening and resolution process for ID indications is summarized in the logic chart in Figure 5-1 and the process for OD indications is summarized in the logic charts in Figures 5-2 and 5.3.

Data sheets and printouts of the results of each examination performed on each penetration are found in Volume 3.

Results from the TOFD ultrasonic and eddy current examinations of the seventy-eight CRDM penetrations and head vent line identified no indications characteristic of PWSCC.

**Figure 5-1 - Penetration Tube ID Indication Screening**

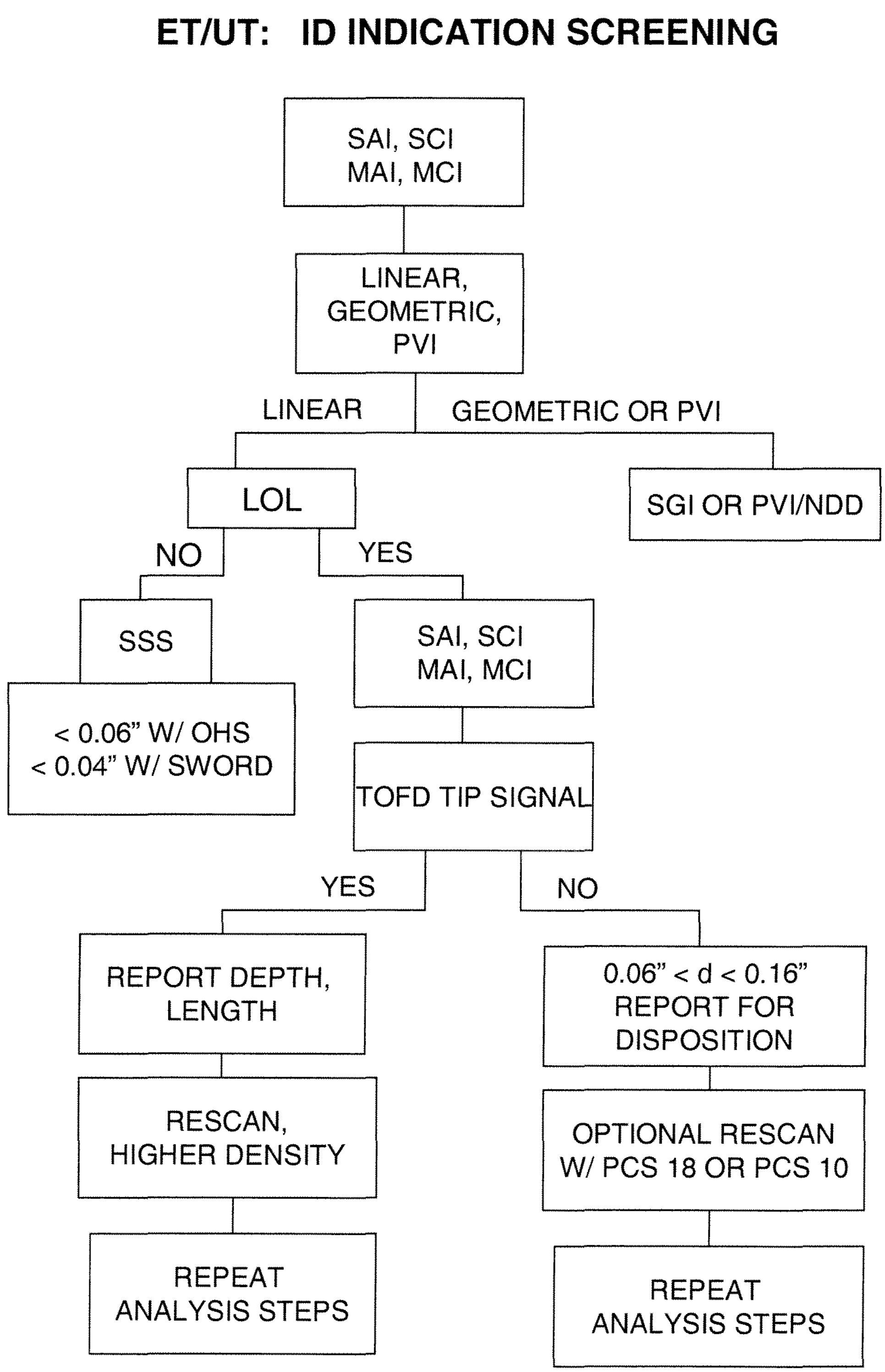


**Figure 5-2 - Penetration Tube OD Indication Screening Within Weld Zone**

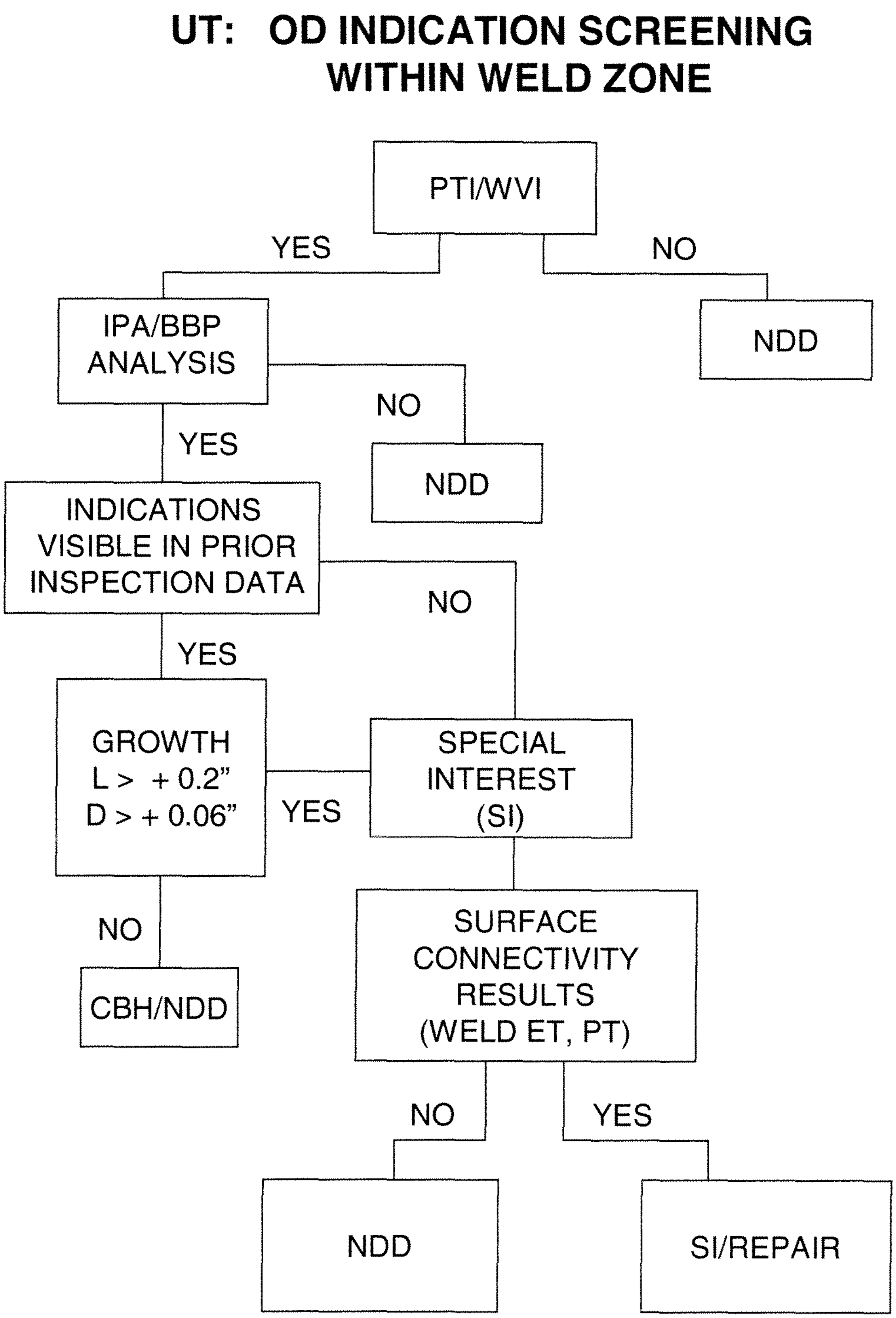
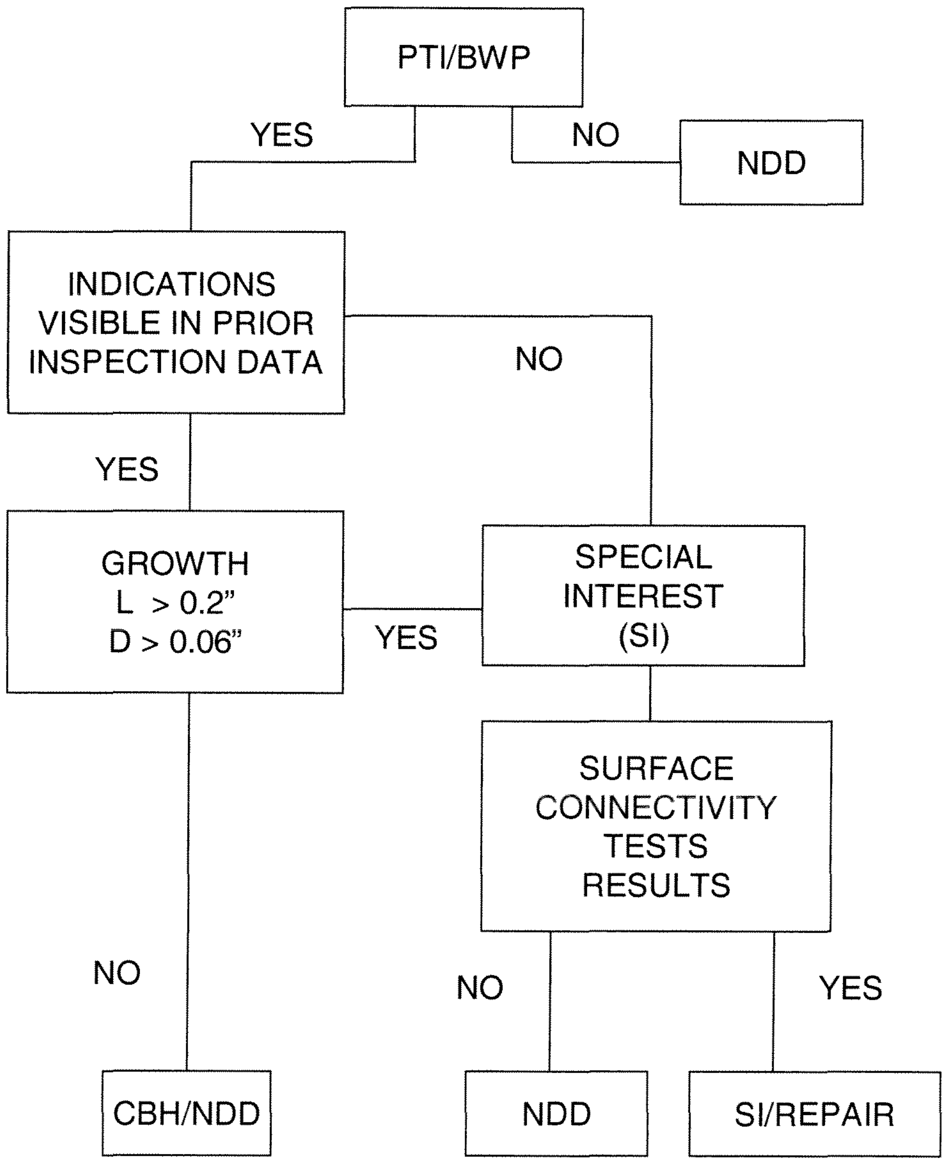


**Figure 5-3 - Penetration Tube OD Indication Screening Above or Below Weld Zone**

## UT: OD INDICATION SCREENING ABOVE/BELOW WELD ZONE



## 6.0 REFERENCES

[1] EPRI/MRP89 Technical Report, "Materials Reliability Program: Demonstrations of Vendor Equipment and Procedures for the Inspection of Control Rod Drive Mechanism Head Penetrations (MRP-89)", EPRI, Palo Alto, CA: July, 2003.

[2] USNRC Letter EA-03-009, "Issuance of First Revised NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Vessel Heads at Pressurized Water Reactors", February 20, 2004.

[3] WCAP-16394-P, Rev. 0, "Structural Integrity Evaluation of Reactor Vessel Head Penetrations to Support Continued Operation: Byron and Braidwood Units 1 and 2", Westinghouse Electric Company LLC, February 2005.

# Appendix A: Braidwood Unit 1 RVHI Exam Coverage Summary

Table A lists the coverage achieved above and below the J-Groove welds on the OD surfaces of each penetration tube location. This table incorporates the procedure, WDI-UT-013, Rev.10.

At all 78 penetration locations, coverage above the welds exceeded 2.0 inches above the highest point of the root of the J-Groove weld.

Coverage extends at least 1.0" below the lowest point at the toe of the J-Groove welds at all penetrations except # 42, 49, 54, 63, 65, 66, 71, 72, 77, and 78.

| Pen # | Coverage Below the Weld @ 0° | 1.0" Below Weld @ 0° | Coverage Above the Weld @ 180° | 2.0" Above Weld @ 180° |
|---|---|---|---|---|
| | Measured in inches | Y or N | Measured in inches | Y or N |
| 1 | 1.28 | Y | 3.84 | Y |
| 2 | 1.36 | Y | 3.92 | Y |
| 3 | 1.52 | Y | 3.20 | Y |
| 4 | 1.48 | Y | 3.76 | Y |
| 5 | 1.52 | Y | 3.66 | Y |
| 6 | 1.52 | Y | 3.88 | Y |
| 7 | 1.56 | Y | 3.64 | Y |
| 8 | 1.56 | Y | 3.72 | Y |
| 9 | 1.44 | Y | 3.96 | Y |
| 10 | 1.72 | Y | 4.48 | Y |
| 11 | 1.88 | Y | 4.48 | Y |
| 12 | 1.80 | Y | 4.64 | Y |
| 13 | 1.68 | Y | 4.36 | Y |
| 14 | 1.40 | Y | 4.00 | Y |
| 15 | 1.28 | Y | 2.84 | Y |
| 16 | 1.28 | Y | 3.92 | Y |
| 17 | 1.36 | Y | 4.00 | Y |
| 18 | 1.84 | Y | 4.44 | Y |
| 19 | 1.64 | Y | 4.84 | Y |
| 20 | 1.56 | Y | 3.76 | Y |
| 21 | 1.60 | Y | 3.96 | Y |
| 22 | 1.40 | Y | 4.36 | Y |
| 23 | 1.60 | Y | 4.56 | Y |
| 24 | 1.72 | Y | 4.52 | Y |
| 25 | 1.48 | Y | 4.60 | Y |
| 26 | 1.48 | Y | 3.76 | Y |
| 27 | 1.52 | Y | 3.76 | Y |
| 28 | 1.40 | Y | 4.00 | Y |

| Pen # | Coverage Below the Weld @ 0° | 1.0" Below Weld @ 0° | Coverage Above the Weld @ 180° | 2.0" Above Weld @ 180° |
|---|---|---|---|---|
| | Measured in inches | Y or N | Measured in inches | Y or N |
| 29 | 1.16 | Y | 4.24 | Y |
| 30 | 1.24 | Y | 4.16 | Y |
| 31 | 1.48 | Y | 4.08 | Y |
| 32 | 1.36 | Y | 4.04 | Y |
| 33 | 1.48 | Y | 3.96 | Y |
| 34 | 1.28 | Y | 4.24 | Y |
| 35 | 1.28 | Y | 3.80 | Y |
| 36 | 1.20 | Y | 4.04 | Y |
| 37 | 1.08 | Y | 4.72 | Y |
| 38 | 1.24 | Y | 4.00 | Y |
| 39 | 1.64 | Y | 3.72 | Y |
| 40 | 1.32 | Y | 4.56 | Y |
| 41 | 1.12 | Y | 4.72 | Y |
| 42 | 0.92 | N | 4.08 | Y |
| 43 | 1.20 | Y | 4.36 | Y |
| 44 | 1.24 | Y | 3.76 | Y |
| 45 | 1.60 | Y | 4.04 | Y |
| 46 | 1.16 | Y | 4.08 | Y |
| 47 | 1.36 | Y | 4.48 | Y |
| 48 | 1.04 | Y | 4.84 | Y |
| 49 | 0.76 | N | 4.32 | Y |
| 50 | 1.04 | Y | 4.32 | Y |
| 51 | 1.40 | Y | 3.92 | Y |
| 52 | 1.44 | Y | 4.00 | Y |
| 53 | 1.24 | Y | 4.04 | Y |
| 54 | 0.92 | N | 4.76 | Y |
| 55 | 1.20 | Y | 4.00 | Y |
| 56 | 1.44 | Y | 3.84 | Y |
| 57 | 1.16 | Y | 3.80 | Y |
| 58 | 1.24 | Y | 4.12 | Y |
| 59 | 1.04 | Y | 4.28 | Y |
| 60 | 1.08 | Y | 4.28 | Y |
| 61 | 1.08 | Y | 4.88 | Y |
| 62 | 1.24 | Y | 5.04 | Y |
| 63 | 0.92 | N | 3.80 | Y |
| 64 | 1.04 | Y | 4.12 | Y |
| 65 | 0.92 | N | 4.52 | Y |
| 66 | 0.92 | N | 4.36 | Y |
| 67 | 1.00 | Y | 4.04 | Y |
| 68 | 1.04 | Y | 4.04 | Y |

| Pen # | Coverage Below the Weld @ 0° | 1.0" Below Weld @ 0° | Coverage Above the Weld @ 180° | 2.0" Above Weld @ 180° |
|---|---|---|---|---|
| | Measured in inches | Y or N | Measured in inches | Y or N |
| 69 | 1.20 | Y | 4.08 | Y |
| 70 | 1.04 | Y | 4.68 | Y |
| 71 | 0.88 | N | 4.40 | Y |
| 72 | 0.92 | N | 4.68 | Y |
| 73 | 1.00 | Y | 4.96 | Y |
| 74* (see note below) | 1.08 | Y | 4.20 | Y |
| 75 | 1.36 | Y | 6.12 | Y |
| 76 | 1.12 | Y | 4.24 | Y |
| 77 | 0.92 | N | 4.32 | Y |
| 78 | 0.84 | N | 4.56 | Y |

* During inspection of penetration 74, the open housing scanner shoe lifted off from approximately 0 to 60 degrees, just above the weld. An informational boroscope video recording was performed via manual jump to view the areas of concern. The pictures below show these areas; with the picture on the left showing small deposits and the picture on the right showing a larger deposit. A letter was transmitted to Exelon under CCE-06-41 which contains the NDE coverage evaluation and crack growth assessment for a sub surface flaw. Between ECT and UT, there was enough coverage to preclude the existence of any surface connected indications on the ID. Since ID coverage has been obtained, primary water stress corrosion cracking (PWSCC) is not a concern. Available leak path results showed no suspect areas. Per CCE-06-41, the valid assumption for a crack in this region would be due to fatigue, which exhibits much slower crack growth rates relative to that due to PWSCC. Refer to CCE-06-41 for more information on this.